

X-RAY CLUSTER PROPERTIES IN SPH SIMULATIONS OF GALAXY CLUSTERS

R. Valdarnini,¹

¹*SISSA, Via Beirut 2-4 34014, Trieste Italy*

Abstract Results from a large set of hydrodynamical SPH simulations of galaxy clusters in a flat LCDM cosmology are used to investigate cluster X-ray properties. The physical modeling of the gas includes radiative cooling, star formation, energy feedback and metal enrichment that follows from the explosions of SNe type II and Ia. The metallicity dependence of the cooling function is also taken into account. It is found that the luminosity-temperature relation of simulated clusters is in good agreement with the data, and the X-ray properties of cool clusters are unaffected by the amount of feedback energy that has heated the intracluster medium (ICM). The fraction of hot gas f_g at the virial radius increases with T_X and the distribution obtained from the simulated cluster sample is consistent with the observational ranges.

Keywords: SPH simulations, heating of the ICM.

1. Introduction

There is a wide observational evidence (Allen & Fabian 1998; Markevitch 1998) that the observed cluster X-ray luminosity scales with temperature with a slope which is steeper than that predicted by the self-similar scaling relations ($L_X \propto T_X^3$). This implies that low temperature clusters have central densities lower than expected (Ponman, Cannon & Navarro 1999). This break of self-similarity is usually taken as a strong evidence that non-gravitational heating of the ICM has played an important role in the ICM evolution. A popular model which has been considered as a heating mechanism for the ICM is supernovae (SNe) driven-winds (White 1991). An alternative view is that radiative cooling and the subsequent galaxy formation can explain the observed $L_X - T_X$ relation because of the removal of low-entropy gas at the cluster cores (Bryan 2000). In this proceedings I present preliminary results from a large set of hydrodynamical SPH simulations of galaxy clusters. The physical modeling of the gas includes a number of processes (see later), and the simula-

tions have been performed in order to investigate the consistency of simulated cluster scaling relations against a number of data.

2. Simulations and results

Hydrodynamical TREESPH simulations have been performed in physical coordinates for a sample of 120 test clusters. A detailed description of the procedure can be found in Valdarnini (2003, V03). The cosmological model is a flat CDM model, with vacuum energy density $\Omega_\Lambda = 0.7$, matter density parameter $\Omega_m = 0.3$ and Hubble constant $h = 0.7 = H_0/100 \text{ Kmsec}^{-1} \text{ Mpc}^{-1}$. $\Omega_b = 0.019h^{-2}$ is the value of the baryonic density. The clusters are the 120 most massive ones identified at $z = 0$ in a cosmological N -body run with a box size of $200h^{-1} \text{ Mpc}$. The virial temperatures range from $\sim 6 \text{ KeV}$ down to $\sim 1 \text{ KeV}$. The simulations have $N_g \simeq 70,000$ gas particles. The cooling function of the gas particles also depends on the gas metallicity, and cold gas particles are subject to star formation. Once a star particle is created it will release energy into the surrounding gas through SN explosions of type II and Ia. The feedback energy (10^{51} erg) is returned to the nearest neighbor gas particles, according to its lifetime and IMF. SN explosions also inject enriched material into the ICM, thus increasing its metallicity with time.

Observational variables of the simulated clusters are plotted in Fig. 1 as a function of the cluster temperature T_X . Different symbols are for different redshifts ($z = 0$, $z = 0.06$ and $z = 0.11$). For the sake of clarity, not all the points of the numerical sample are plotted in the figure. Global values $A_{Fe} = M_{Fe}/M_H$ of the iron abundances for the simulated clusters are shown in panel (a). A comparison with real data of a small sample subset (four clusters, see V03) shows a good agreement with the measured values. The values of A_{Fe} appear to increase with T_X , even though the observational evidence of an iron abundance increasing with T_X is statistically weak (Mushotzky & Lowenstein 1997).

The fraction of hot gas $f_g = M_g/M_T$ is defined within a given radius as the ratio of the mass of hot gas M_g to the total cluster mass M_T . The fraction f_g has been calculated at a radius enclosing a gas overdensity of $\delta = 500$ relative to the critical density. The values of f_g of the numerical cluster sample are plotted in panel (b). There is a clear tendency for the f_g distributions to increase with cluster temperature. This is in accord with theoretical predictions of the radiative cooling model (Bryan 2000), and with numerical simulations (Muanwong et al. 2002 ; Dave et al. 2002). A subsample of the f_g distribution at $z = 0$ is found to be statistically consistent (V03) with the data of Arnoud & Evrard (1999). Furthermore, Sanderson et al. (2003) found strong observational evidence for a dependence of f_g with T_X .

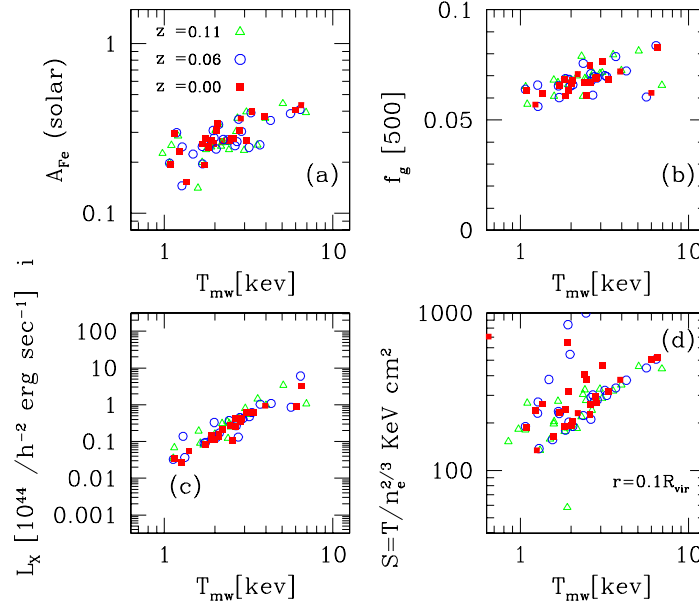


Figure 1. (a): Average iron abundances of the simulated cluster sample at $r = 0.5h^{-1}Mpc$ are plotted versus cluster temperatures. Different symbols refer to different redshifts. (b): As in panel (a), but for the gas fractions $f_g = M_g(< r)/M_T(< r)$; the fractions are evaluated at the radius within which $\rho/\rho_c = \delta$, with $\delta = 500$. (c): Bolometric X-ray luminosities are plotted as a function of the temperature. (d): Cluster core entropies $S(r) = k_B T(r)/n_e(r)$ at the radius $r = 0.1r_{vir}$ are shown against cluster temperatures.

The values of the bolometric X-ray luminosity L_X are shown in panel (c) as a function of the cluster temperature. Mass-weighted temperatures have been used as unbiased estimators of the spectral temperatures (Mathiesen & Evrard 2001). A central region of size $50h^{-1}Kpc$ has been excised (Markevitch 1998) in order to remove the contribution to L_X of the central cooling flow. The L_X of the simulations at $z = 0$ are in good agreement with the data (V03) over the entire range of temperatures. An additional run has been performed for the cluster with the lowest temperature, but with a SN feedback energy of 10^{50} erg for both SNI and Ia. The final L_X of the run is very similar to that of standard run. This demonstrates that the final X-ray luminosities of the simulations are not sensitive to the amount of SN feedback energy that has heated the ICM.

The core entropies of the clusters are displayed in panel (d) against the cluster temperatures. The cluster entropy is defined as $S(r) = k_B T(r)/n_e(r)$, where n_e is the electron density. The core entropy is calculated at a radius which is 10% of the cluster virial radius. The result indicates that for low temperatures part of the sample has clusters with core entropies which approach a floor at $\sim 100 \text{ keV cm}^{-2}$, while for some clusters the decline of entropy with temperature is steeper and close to the self-similar predictions ($S \propto T$). This different behaviour could be due to the different dynamical histories of the clusters. It is worth stressing that for all the plotted quantities there is little evolution below $z = 1$.

To summarize, simulation results give final X-ray properties in broad agreement with the data. These findings support the so-called radiative model, where the X-ray properties of the ICM are driven by the efficiency of galaxy formation rather than by the heating due to non-gravitational processes.

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